DEVELOPMENTAL CHANGES IN CORTICAL PROCESSING AS REFLECTED BY VISUALLY EVOKED POTENTIAL VARIABILITY

By

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1978

ACKNOWLEDGEMENTS

I would like to express grateful appreciation, respect, and affection to Dr. Nathan W. Perry, Jr., for his firm, but unintrusive, support and guidance in all of my graduate education endeavors. Many thanks to Dr. Robert L. Isaacson for continually whetting my research taste buds, and to Drs. Wiley Rasbury and Vernon Van De Riet for their personal interest in me as a human being. Thanks to Dr. Donald Childers, who pointed out to me the difference between a fact and a piece of data.

I am extremely grateful to Drs. Bill Cleveland and Dee Ramm, of the Duke University Medical Center, for their unselfishness with their time and statistical and computer expertise. I would also like to thank Denise Dixon for her patience and promptness in typing the manuscript, and Helen Corless for the figure drawings.

Family and friends provided immeasurable emotional support over the years; most particularly, I am grateful to my parents, Joan Duer, Peggy Brooks, and Clif Dopson for their encouragement of me to finish without ever pushing too hard.

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Graduate Council of the University of Florida
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

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March 1978

Chairman: Nathan W. Perry, Jr.
Major Department: Clinical Psychology

There is general agreement that the variability, or flexibility, seen in perceptual and intellectual response patterns is important to the understanding and predictability of behavior. In this study the variability of cortical processing over time is investigated using visually evoked response (VER) standard deviations as a measure of variable cortical processing. Since VERs are felt to reflect the sequence of neural events that occur as a visual stimulus is perceived and processed by the brain, VER variability is felt to reflect the variability of cortical processing.

The subject population in this study consisted of 76 children who participated in the study for three years

starting when they were in kindergarten. All the children had normal visual acuity. The sample was homogeneous with respect to socio-economic status. VERs were collected for each subject in response to four different stimulus conditions and recorded from three or four scalp locations. The variability measure derived was the standard deviation (SD) statistical measure. This was derived for each whole VER response, and one each for the early, middle, and late components of each VER.

Upon determining that the control SD data were significantly different from the other SD data, SD changes over the years were examined across the whole VER for each stimulus condition and location. Significant changes were found from year 1 to year 3, and year 2 to year 3. Most changes seen were a decrease in variability over time, except for an increase from year 2 to year 3 at the parietal lobe location. The overall analysis of change in the variability of the VER components over time was not statistically significant, but the pattern was the same as that for the whole VERs of a decrease in variability over time except for an increase at the parietal lobe location from year 2 to year 3. There were differences between the components within years, but the differences were consistent over time. Changes in variability of the whole VERs over time as a function of sex were examined. The overall effect was not statistically significant, but the females, in almost all conditions, demonstrated more VER

variability than the males. Also, the females demonstrated a pattern similar to that of the total sample in that a steady decrease in variability was seen across years, except for the parietal lobe which showed an increase from year 2 to year 3. However, the males showed an increase in variability from year 1 to year 2 and a decrease from year 2 to year 3 at all electrode locations.

The major finding of a consistent change in variability over time in the total sample as measured by whole VER SD indicated a significant decrease in variability of cortical processing from age five to age seven and age six to age seven, except for the cortical functioning detected at the parietal lobe which indicated an increase in variability. These findings are consistent with, and extend, the previous findings in the VER literature. The findings are related to the literature on child cognitive development. It is suggested that the decrease in VER variability is indicative of cognitive processing that is mature or practiced and that the increase in variability at the parietal lobe is indicative of a currently active or developing cognitive function. Similarly, a difference in rate of growth of different cortical processes or basic differences in cortical processing itself are hypothesized in reference to the sex differences found. The data provide the beginning of baseline data for normal

changes in cognitive flexibility which may eventually be used to help assess abnormal child growth and development.

SECTION I
INTRODUCTION

The central nervous system is characterized by ongoing intrinsic electrical activity which is described by the electroencephalogram (EEG). When this activity is measured in response to a large number of presentations of light flashes averaged together, the response change produced is called a visual evoked response (VER). The response to an individual flash is small and cannot ordinarily be visually detected apart from the ongoing activity; therefore, the responses to a large number (50-100) of light flash presentations are averaged together by computer. The averaging process results in an electrical response that is easily identified. Widely accepted today is the thought that neural structure and function underlie mental processes. The described VER has been proposed and used as an indicator of neural functioning and mental processing; the VER is felt to reflect in part the sequence of cortical events that occur as a visual stimulus is perceived and processed by the brain (Perry & Childers, 1969).

Several parameters of the VER, usually amplitude and latency, have been derived and used to investigate brain functioning that occurs during visual stimulation.

Developing from these investigations has been interest in another parameter, variability, as an indicator of cortical functioning, specifically cortical processing variability (Brazier, 1964; Callaway, 1975; Ellingson, 1970). Although much of the theory and research on the development of specific cortical functions concentrates on the maturation of stable, constant response patterns, there is general agreement that the variability seen in response patterns is also important to development (Callaway, 1975). Essential to the understanding and predictability of behavior, in this instance cortical processing, is knowing its patterns and changes over time. The existence of critical points of brain and behavior change may be detected not only through patterns of continuity and stability, but through patterns of instability and flexibility. Thus, VER investigations, including ones measuring some form of variability, have been done in order to better understand the cognitive organization of brain-behavior relationships.

VER investigations have progressed on the assumption that the patterns produced may be more accurate reflections of cognitive substrates than currently used performance measures of mental processing. An investigation of VER data of five year olds using a factor analysis procedure indicated that the VER is multidimensional in nature (Street, Perry, & Cunningham, 1976). That is, several

different aspects of VER are functioning together at any one time to contribute to the final detected signal. Thus, if the resulting VER actually consists of a variety of ongoing functions, investigations of the variability of cognitive processing may lead to more accurate determinations of the functional contribution of the different aspects of the VER over time. Since measures of VER variability are assumed to reflect variability in cognitive processing, they may be used to more accurately correlate neurophysiological processes with cognitive behavioral processes.

There is strong evidence to indicate that aspects of the VER are correlated with cortical processing. Early work using the VER as an electrophysiological measure of cognitive ability found high IQ scores to be associated with short VER latency in later components (Chalke & Ertl, 1965). This finding has subsequently been replicated several times: Bigum, Dustman, and Beck (1970) found later component latencies to be significantly later ($p < .05$) in mongoloids than in normal subjects, and Shucard and Horn (1972) found correlations from -.15 to -.32 between latency and cognitive abilities. Several studies have found higher amplitudes in brighter children and adults than in less bright people (Bigum et al., 1970; Rhodes, Dustman, & Beck, 1969). Amplitude and latency of VER components are the characteristics

usually used to make correlations with intelligence, but it has been suggested that VER variability might be an important phenomenon of evoked potentials (Brazier, 1964; Callaway, 1975).

Several VER studies, not all of which are developmental in nature, have investigated VER variability, although the variability examined is often differently defined and measured across studies. Among 20 normal adults the greatest VER variability was found between subjects, next between areas of the head, and least across time within an individual (Werre & Smith, 1964). In another study on 20 normal adults, Cigánek (1969) saw a decrease in amplitude variability after 80 msec and an increase in variability in early latency waves. He also found the amplitude variability of the EP (evoked potential) to be negligible between the averaged responses of individual subjects, although high across the whole group of subjects. In a study of five adults, Robinson (1975) demonstrated that attentive viewing as compared to passive viewing produced a decrease in amplitude variance of a particular VER.

Although most of the studies with psychiatric patients do not control for level of intellect, the evoked response findings suggest a correlation between variability and thought disorders. Among psychiatric patients, psychotic depressives showed greater variability

compared to other subgroups (Borge, 1973). Schizophrenics as compared to normals had more variable VERs in response to different stimulus intensities (Rappaport, Hopkins, Hall, Belleza, & Hall, 1975). Schizophrenic adults, some of whom were said to have a thought-process disorder, showed greater variability of auditory evoked potentials (based on correlations between AERs to different stimuli) than normal subjects (Callaway, Jones, & Donchin, 1970). Callaway and Jones conclude from another study that variable evoked potentials are correlated with variable and unstable cognitive functioning (1975). Lifshitz (1969) found that schizophrenics showed more variability than normals to simple (visual) and compound (visual and auditory) stimuli. Among schizophrenics, EP variability (also based on between-EP correlations) is greatest in those who show inaccurate and variable perceptual performances (Inderbitzen, Buchsbaum, & Silverman, 1970).

Brazier (1964) was the first to look at variability of the separate responses that are usually summed to form a VER. She found variability to be greater in the first 30 responses in a train of 300 than the last 30, when habituation was said to have occurred. Barnet and Lodge (1967) examined the unaveraged individual auditory evoked responses of 15 mongoloid and 55 normal subjects under 14 months of age and saw great variability in the amplitudes, but found the mongoloids to have many more

extremely large responses and to show less decline in response stimulation with repetitive stimulation than the normal subjects. This suggests differences in brain mechanisms governing sensory input.

Ellingson (1970) has done much work in the area on infant VER variability and, overall, has found neonatal VER variability to be high. Although he does not explain mathematically how he measures variability, he states that individual neonatal VERs, in contrast to the findings in adults, were often variable in latency and amplitude during a single recording session. In one study the mean latencies of components of averaged auditory evoked potentials were compared between sleeping children; younger children's AERs were found to be more variable than older children's (Barnet, Ohlrich, Weiss, & Shanks, 1975).

Callaway (1975) hypothesized that if evoked potentials reflect cognitive processes, then habitually irregular or unstable modes of cognitive processing should be accompanied by variable evoked potentials. In a 1969 study (Callaway & Stone) samples were described in which normal adults showed low variabiliy VERs, schizophrenics had intermediate values, and children (aged nine) had high variability. Data on the children showed that lower evoked response variability tended to be correlated with higher scores on a visual-motor integration test. In another developmental

study done with visual and auditory evoked potentials, variability of the EPs of 119 children from ages six to 15 were investigated (Callaway & Halliday, 1973). Variability decreased with increasing age. Further investigations with the Beery Visual-Motor Integration test (1967) led Callaway to conclude that EP stability is sufficient, but not necessary, for good cognitive task performance (1975). In several studies with normal adults, Callaway (1975) found high EP variability to be correlated with low verbal IQ. He hypothesized that, in general, decreasing variability with increasing age might be due to an increasing stability of cognitive functioning with age.

Thus, VER variability has been used as a measure of change, sometimes between VERs across subjects and conditions, and sometimes between responses making up a VER within a subject. Another way to consider VER variability is to study the differences between early and late components of the VER. The VER waveform is considered to be composed of a number of components, or positive and negative amplitude deflections. It has been postulated that early components represent primary sensory system activity and processing of the physical parameters of the stimulus (John, Ruchkin, & Villegas, 1964; Ertl, 1969). Ertl (1969) states that the late components of the AEP are sensitive to changes in

stimulus parameters involving decision-making (Sutton, Braun, Zubin, & John, 1965), pattern recognition, attention, and problem solving (Beinhocker, Brooks, Anfenger, & Copenhaver, 1966; Callaway, 1966; Chapman, & Bragdon, 1964; Uttal, 1965), drug-inducing changes in levels of alertness (Allison, Goff, Abrahamian, & Rosner, 1963; Brazier, 1963; and Garcia-Austt, 1963), and generally the informational content of the stimulus. Buchsbaum feels that, because later components of EPs (after 200 msec) change more than earlier ones as a function of attention, arousal, and expectancy, greater experiential effects might be expected in late components (1974). He also suggests that early components may be more stable and genetically determined. Callaway and Halliday (1973) found the variability of late EP components (100 msec or later) decreasing with increasing age more than the variability of earlier components. Their findings suggest that by age six a child's sensory processing is stable, but higher perceptual information processing is still stabilizing. Barnet et al. (1975) found that decreases in the latencies of the various components proceeded at different rates and felt that this suggested that the components reflect independent neural substrates. They also noted that the components of shortest latency displayed the weakest relationship to age. Apparently, not only the variability of the whole VER, but the

variability of its components gives an indication of changing cortical processing.

As was previously noted, studies in the area of VER variability are sometimes difficult to compare since variability may be conceived of in several different ways. For example, one is measurement, or experimental, variability which, in most studies, is assumed to be controlled for and, therefore, not contributing in a large part to detected variability. Variability in cortical processing may also be examined. This may be thought of as consisting of two parts: one is a structural variability in that the structure, or physical parameters, of the sensory system and/or the stimulus itself may be variable; the other part is a functional variability referring to variability, or flexibility, in cortical processing of input--such changes are felt to reflect processing variability at a level higher than the primary sensory level. Developmental variability is also examined and may also be thought of as consisting of two parts: variability may be apparent as basic structures develop, and when functioning develops after the physical structure is clear.

Of major interest here is VER variability reflecting cortical reorganization as a function of developmental processes. It has been long established that most physical and structural changes have occurred by this age range (five to seven years) (Yakovlev & Lecours, 1967); therefore,

variability changes seen will be investigated as indicators of cortical processing changes and/or functional developmental changes in processing.

The age range chosen is an important one to investigate not only because of the scarcity of VER variability data on this group, but also because of the important cognitive changes reportedly occurring at this time. White (1965) has postulated that the five to seven age range is a significant one for changes in particular learning paradigms. Piaget (1962) stressed the increasing flexibility of thinking and the resultant acquisition of certain forms of conservation from the ages four to seven. In general, ideas and research in the developmental area indicate that response patterns go through a period of increasing flexibility for proper adaptation to the changing environment, but at some point the flexibility either decreases or becomes more selective. If, as expected, the VER variability measure is useful as an indicator of normal growth and development of cognitive processing, the timely significance of the study becomes apparent. As a predictor and diagnostic tool the measure may be useful in the detection of and therapeutic intervention in problems of child development, such as hyperactivity (Halliday, Rosenthal, Naylor, & Callaway, 1976) and specific reading disability (Preston, Guthrie, Kirsch, Gertman, & Childs, 1977).

It is felt that the variability measure provides a picture of changing cognitive functioning and an index to the developmental stages of differentially maturing functions of the central nervous system.

In order to assess developmental changes in cortical reorganization during this important age range, VER variability measures were collected in a longitudinal study of children over a three year span, variability is expected to show a change in direction indicative of functional changes in cortical and developmental processing. Variability measures are derived on VERs collected over the three years under several stimulus conditions and from several cortical locations. VERs in response to different frequencies of stimulation and to different stimulus characteristics (pattern or diffuse) are expected to show differences in variability, as the brain may be expected to respond more or less variably depending on the complexity of the stimulus. Variability derived from different brain locations is expected to differ as some are more purely perceptual and may be at different developmental stages over the three years. VER variability of early, middle, and late components is expected to differ as these components are thought to represent different stages and functions of cortical processing. Since early components are thought to represent simple sensory processes which

reach full development relatively early, they are expected to show less VER variability over time than the later components, which are thought to represent processing at a higher level of complexity not yet completely developed. The change in variability over time will also be compared between males and females to investigate possible sex differences, since, at this age range, sex differences in specific cognitive abilities have been found (Mussen, 1970).

SECTION II
METHOD

Subjects

Letters describing the study and asking for participation were sent to parents of all children entering kindergarten in 1973 in the city of Gainesville, Flordia. Those parents who responded were contacted and their child was accepted in the study if (a) the family had no plans to move within three years and (b) the child had no unusual medical or developmental history. The subject sample for this study consisted of 76 white children (37 females, 39 males) with complete data for three years. Attrition from the original sample of 98 was nine and another 13 had incomplete data due to occasional equipment and/or collection difficulties. During the first year of data collection the mean age was 67.3 months (SD=2.9, range=62-75 months), 79.2 months (SD=2.6, range=74-85 months) during the second year, and 91.8 months (SD=2.7, range 86-100 months) during the third year. The mean full score IQ (WPPSI) for the first year was 118.8 (SD=9.5, range=94-144), the mean full score IQ (WISC-R) for the second year was 114.2 (SD=11.4, range=84-141), and

the mean full score IQ (WISC-R) for the third year was 120 (SD=11.4, range=83-142). All children had normal visual acuity in each eye (Snellen "E") and normal stereopsis (Titmus "Fly"). The sample was relatively homogeneous and upper middle-class with respect to socio-economic status, with, for example, 16.6% of the mothers and 65% of the fathers holding advanced degrees and most families having an income in the range of 10-20 thousand dollars.

VER Testing Procedure

Silver-silver chloride cup electrodes and paste (Beckman) were placed on the scalp at locations C_3, C_4, O_z, and P_z of the international 10-20 electrode system (Jasper, 1958). The central locations (C_3 and C_4), sampling left and right hemispheres, were referenced to linked ear lobes. The occipital location was a bipolar derivation between O_z and P_z, on the midsaggital plane. After the first year a fourth location over the left parietal (P_3) was added. Impedances of approximately 2 Kυ were obtained between electrodes, as measured with a d.c. impedance tester (IMA Electronics).

Each subject was seated in an adjustable ophthalmic chair in an electrically shielded and light-proof room (ACE). Ventilating blowers produced a steady 62 dB noise level (General Radio 1551-A) to mask equipment and extraneous noise. Solid state d.c.-powered differential

amplifiers were placed inside the shielded room near the subject, enabling the use of very short electrode leads (Microdot). Following amplification, electrical activity was filtered (1.0 to 50 Hz, Krohn-Hite 330 BR) and simultaneously routed to an FM tape recorder (Sanborn 7000) and in year 1 averaged by a CAT computer and subsequently by a Nicolet MED-80 averaging computer. Frequency response of the complete recording system was relatively flat from 2.0 Hz to 30 Hz, and was 50 percent attenuated at 1 Hz and 50 Hz. A 5 μV calibrate signal (Medistor C-1A) was introduced through the amplifiers for each subject and processed in the same manner as the VERs. Each VER was the result of sixty 500-msec sweeps of the computer.

Throughout the VER session of approximately 25 min., subjects viewed binocularly a 6° (visual angle) circle of achromatic light, continuously illuminated to provide a background level of 0.1 log ft.-L. (SEI photometer). The continuous background and the stimuli were provided by four projectors (Viewlex V-120), mounted outside the shielded room and projecting through a double plexiglas conductive window (Tecknit) just above and behind the subject's head. The stimuli were projected onto an aluminized screen located eight feet in front of the subject. Electronic shutters (Gerbrands) attached to each projector determined stimulus durations. During stimulation, eye fixation of subjects was aided by a chin

rest and monitored by an experimenter seated obliquely in front of the subject. Fixation upon the center of the circle was required for 30 sec for each trial. Loss of fixation (greater than about 2^{o}) resulted in aborting and repeating the VER averaging.

Three different stimulation conditions were used, in order to obtain VERs reflecting presumably different types of cortical processing. For the first stimulus condition, 2 Hz diffuse, light flashes were presented at a rate of 2/sec for 30 sec (giving 60 flashes). The flashes, of 50 msec duration, were superimposed on the 6^{o} background circle, and were functionally diffuse since, other than the dim background illumination, the room was dark.

The second stimulus condition, 6 Hz diffuse, consisted of a 15 msec-duration flash superimposed on the 6^{o} background at a rate of 6/sec for 30 sec (giving a total of 180 flashes, with the responses averaged over 60 sweeps of 500 msec each, as in the 2 Hz diffuse condition). Illuminance of the individual flashes in both the 2 Hz diffuse and 6 Hz diffuse conditions was 2.35 log ft.-L.

There is evidence that diffuse light, as used in the 2 Hz diffuse and 6 Hz diffuse conditions, is processed differently from pattern stimulation by the cortex (Hubel & Wiesel, 1962; Perry & Childers, 1969). To see what effect pattern stimulation might have on the variability

of cortical processing the third stimulus condition was the presentation of 2 Hz pattern. The pattern was a 6° "sunburst," with a dark 14' center from which an equal number of light and dark rays extended, each of which subtended 30' at the circumference. The pattern was superimposed on the background circle at an illuminance of 2.2 log ft.-L., and was alternated at a rate of 2/sec with a diffuse 6° circle adjusted to the same apparent brightness. The pattern appeared for 50 msec and disappeared for 450 msec, for a total of 30 sec (60 times), without any apparent change in the brightness of the circle.

In addition to the three stimulus conditions, a control condition was used in which the cortical activity was averaged in the same manner as for the 6 Hz diffuse condition, but with the flashing light occluded so that the subject viewed only the continuously-lit background circle.

Ten 60-sweep VERs (trials) of 500 msec each were collected from each subject, with approximately 2 min between trials. The order of stimulus presentation for the trials was as follows: (1) control; (2) (3) (4) 6 Hz diffuse; (5) 2 Hz pattern; (6) 6 Hz diffuse; (7) 2 Hz pattern; (8) 2 Hz diffuse; (9) 2 Hz pattern; (10) 2 Hz diffuse. This procedure yielded a total of 30 VERs (10 trials by 3 electrode locations) for each subject.

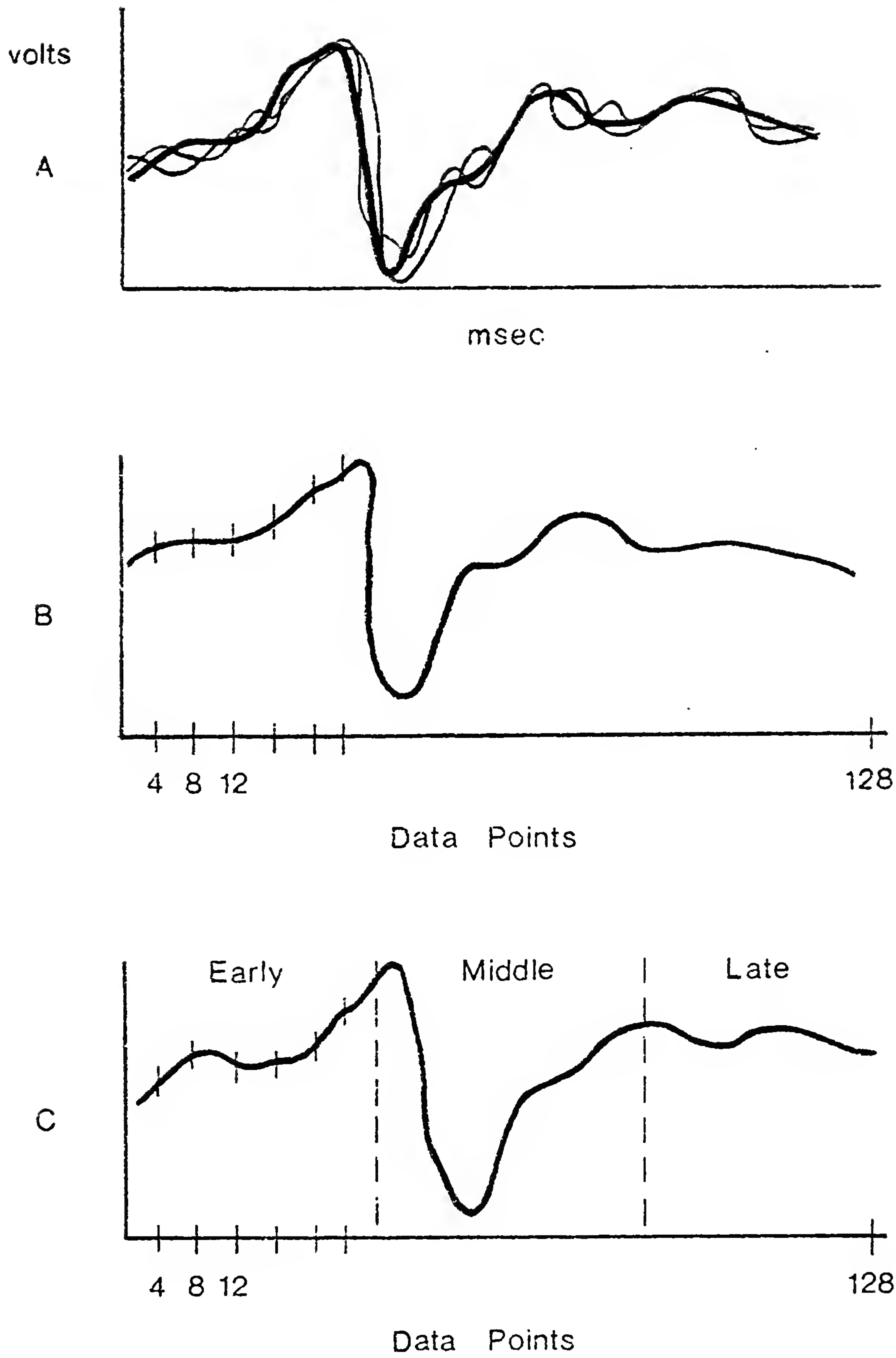
Preliminary Data Processing

VERs for all subjects were first normalized relative to the amplitude of a 5 μV calibration sent through the amplifiers and averaged in the same manner. Pearson product-moment correlations were then performed between common VERs measured from the same electrode location to the same stimulus condition (that is, trials (2) (3) (4) and (6) all at 6 Hz diffuse from the occipital location were correlated, then from the left hemisphere location, then the right hemisphere location, then the left parietal location; trials (5) (7) and (9) all at 2 Hz pattern from the occipital location were correlated, then from each of the other locations; and trials (8) and (10) at 2 Hz diffuse from each of the locations were correlated). VERs from the same location to the same stimulus condition were then pooled for each subject, reducing the 30 VERs to 12 or 16 (3 or 4 locations by 4 conditions including the control trial). As a result, the control VER represents 60 sweeps, each 6 Hz diffuse VER represents 240 sweeps, each 2 Hz pattern VER represents 180 sweeps, and each 2 Hz diffuse VER represents 120 sweeps. Based on these pooled VERs the computer (Nicolet MED-80) was programmed to provide amplitude measures at 128 data points across each VER waveform. Fortunately, the data as described up to this point had been collected as part of a larger longitudinal study conducted by Nathan W. Perry, Jr., Ph.D. The available

amplitude data were then used in this study to derive standard deviation (SD) measures, also using the Nicolet MED-80 computer. The SD program resulted in 32 SDs (one at every fourth point of the 128 data points) for each VER. The 32 SDs were condensed to one SD by converting the 32 SDs back to variances, getting an average variance, and then taking the square root of that value. The VER was also divided into early, middle, and late components based on msec passed. The early component consisted of the VER from 40 to 150 msec, the first 40 msec being dropped as the variance there is felt to reflect experimental error (Perry & Childers, 1969). The middle component was the VER from 151 to 275 msec and the late component was the VER from 276 to 400 msec. The last 100 msec were dropped for the same reason as cited above. A single SD was derived for each of the components of each of the VERs by the averaging process described above, so that there were subsequently four SD measures for each VER: one each for the whole, early, middle, and late VER. The figure illustrates the steps taken to derive the SD measures from the summated amplitude values of the VER waveforms.

It has been suggested (Callaway, 1975) that the amplitude of VERs is highly correlated with the standard deviation(s) of a particular VER; therefore, standard deviations may need to be divided by the VER peak-to-peak

Figure. Pictorial representation of derivation of SDs. (A demonstrates a typical VER waveform at a given location and stimulus condition with summated waves apparent. B demonstrates the computer data points at which the SD measures were derived from the contributing 120-240 available amplitude measures at every fourth point; the 32 resulting SDs were then averaged to get one SD measure per VER waveform. C demonstrates the division of the VER waveform into an early, middle, and late component; the SDs derived from the whole waveform were then averaged within each component to result in three more SD measures per waveform.)


volts
A
msec
B
4 8 12
128
Data Points
Early
Middle
Late
C
4 8 12
128
Data Points

amplitude in a normalizing process. In order to test this hypothesis, the SDs on the first year of data were compared to the SDs divided by the peak-to-peak amplitudes on the first year of data by using a Pearson means correlation procedure. The two variables were found to be largely uncorrelated across the 12 VERs (values ranged from .25 to -.15) suggesting that standard deviations do not need to be divided by the VER amplitudes in order to discuss standard deviation changes. Based on this finding, the rest of these analyses are based on simple standard deviations, not SDs divided by peak-to-peak amplitudes.

Data Analysis

Subsequent analyses were done using the General Linear Models procedure from the SAS statistical program package (1976). This procedure was chosen over other possibilities due to its known reliability and its flexibility in testing procedures. It is basically a linear regression procedure using a least-squares fitting of univariate and multivariate models of regression.

SECTION III
RESULTS

Control Data

Essential to further analyses is a finding of a significant difference between the SD data collected on the control trial and the SD data collected on the experimental trials. As was noted earlier, VERs are felt to reflect cortical activity above and beyond the ongoing intrinsic electrical activity reflected by the EEG. If the SD data from the control trial, in which light was continuous rather than flashing, was not significantly different from the other SD data, then the SD data could be felt to reflect nothing more than the variability of intrinsic processing and methodology. The control SD data were compared to the VER SD data on the first year of data collected at the occipital location. The control data were significantly different ($F(3,73)= 88.19$, $p < .0001$) from the SD data derived from the 6 Hz diffuse occipital condition, the 2 Hz pattern occipital condition, and the 2 Hz diffuse occipital condition.

Whole VER Variability

In order to assess changes in variability over time as evidenced through whole VER SDs the data were examined

by use of the SAS GLM procedure. Changes over the three years were examined separately for each stimulus condition and location and an overall effect was assessed. As can be seen in Table 1, the overall effect was significant at the $p < .0003$ level ($F(21,55)=3.22$). The individual analyses indicated no significant changes in variability from year 1 to year 2, whereas there were changes from year 2 to year 3 and from year 1 to year 3, particularly for the occipital brain location. There were significant changes at the right lobe location for 6 Hz and 2 Hz pattern from year 1 to year 3, but the significant change was at the left lobe location for 2 Hz diffuse. Table 2 shows the mean SD at each year for each VER and the direction of change. Except in a few cases, most of the changes were a steady decrease in variability over time. The changes in the parietal location for all three stimulus conditions were increases from year 2 to year 3 (these changes were not statistically significant). The SD changes at the occipital location for the 2 Hz diffuse condition were the only ones that did not show a linear change; there was an increase from year 1 to year 2 (not a statistically significant change) and a decrease from year 2 to year 3 (this was significant, as was the overall decrease from year 1 to year 3).

Component VER Variability

In order to detect any significant changes in the variability of the early, middle, and late components of

Table 1

Significant SD Changes Over Time for Whole VERs

Condition	Years 1-3	Years 2-3
6Hz diffuse, occipital location (6HzO)	$F(1,75)=16.53$, $p < .0001$	$F(1,75)=24.00$, $p < .0001$
6Hz diffuse, left lobe location (6HzL)		
6Hz diffuse, right lobe location (6HzR)	$F(1,75)=4.48$, $p < .0377$	
6Hz diffuse, parietal location (6HzP)		
2Hz pattern, occipital location (2HzP,O)	$F(1,75)=29.83$, $p < .0001$	$F(1,75)=25.68$, $p < .0001$
2Hz pattern, left lobe location (2HzP,L)		
2Hz pattern, right lobe location (2HzP,R)	$F(1,75)=7.62$, $p < .0073$	
2Hz pattern, parietal location (2HzP,P)		
2Hz diffuse, occipital location (2HzD,O)	$F(1,75)=9.67$, $p < .0037$	$F(1,75)=14.15$, $p < .0003$
2Hz diffuse, left lobe location (2HzD,L)	$F(1,75)=4.42$, $p < .0388$	
2Hz diffuse, right lobe location (2HzD,R)		
2Hz diffuse, parietal location (2HzD,P)		

*overall $F(21,55)=3.22$, $p < .0003$

Table 2

Mean SDs and Directions of Change Over Time for Whole VERs

Condition	Year 1	2	3	Direction	Significant Changes
6HzO	544.5	537.6	485.1	Decrease	yrs. 1-3,2-3
6HzL	496.6	491.4	483.3	D	-
6HzR	495.2	483.5	474.8	D	yrs. 1-3
6HzP	-	487.7	499.9	Increase	-
2HzP,O	614.8	599.4	534.4	D	yrs. 1-3,2-3
2HzP,L	501.1	496.7	484.5	D	-
2HzP,R	505.7	488.9	476.7	D	yrs. 1-3
2HzP,P	-	507.3	512.5	Increase	-
2HzD,O	520.8	527.1	479.5	I-D	yrs. 1-3,2-3
2HzD,L	511.2	506.2	496.1	D	yrs. 1-3
2HzD,R	509.5	498.0	496.3	D	-
2HzD,P	-	498.6	507.1	Increase	-

Note. The unit of measure for the numbers is μV.

the VER over time, and significant differences between the components, the SDs derived on the components were compared using the SAS GLM procedure. In this case, differences between early and middle components were compared between year 1 and year 2 and between year 2 and year 3, and differences between middle and late components were compared between year 1 and year 2 and between year 2 and year 3. First of all, the overall tests of significance done in this procedure indicated no significant differences; therefore, even though some sighificant differences were found on the separate analyses, conclusions based on these findings must be conservative. Table 3 gives the findings based on this analysis. As can be seen, most of the changes in the SDs of the different components over time occur between the second and third years in the 2 Hz pattern conditions and the changes are evident across all three components. Significant changes from year 1 to year 2 were found in the 2 Hz pattern left lobe and the 2 Hz diffuse right lobe conditions. Table 4 shows the mean SDs over time and the directions of change. Similarly to the analysis of the whole VERs, most of the changes are a linear decrease over time, except for the parietal lobe components which show an increase from year 2 to year 3. Also the 2 Hz diffuse occipital condition shows an overall decrease, but an initial increase from year

Table 3

Significant SD Changes Over Time for Component VERs

Condition	Early-Middle Years 1-2	Early-Middle Years 2-3	Middle-Late Years 1-2	Middle-Late Years 2-3
6HzO				
6HzL				
6HzR				
6HzP				
2HzP,O		$F(1,75)=4.79$ $p < .0317$		
2HzP,L	$F(1,75)=4.87$ $p < .0304$	$F(1,75)=9.52$ $p < .0028$		$F(1,75)=4.97$ $p < .0288$
2HzP,R		$F(1.75)=9.40$ $p < .0030$		
2HzP,P				$F(1,75)=8.26$ $p < .0053$
2HzD,O				
2HzD,L			$F(1,75)=3.81$ $p < .0545$	
2HzD,R			$F(1,75)=7.79$ $p < .0067$	
2HzD,P				

*overall $F(42,34)=1.18$, $p < .3095$

Table 4

Mean SDs and Directions of Change Over Time for Component VERs

Condition	Component	Year 1	2	3	Direction
6HzO	E	544.3	535.9	483.5	Decrease
	M	543.4	538.4	484.4	D
	L	546.6	539.2	486.8	D
6HzL	E	495.8	488.7	482.2	D
	M	494.7	492.7	482.3	D
	L	498.3	491.3	486.0	D
6HzR	E	495.4	482.2	475.1	D
	M	497.0	481.9	473.1	D
	L	494.3	484.3	474.5	D
6HzP	E	-	485.6	498.0	Increase
	M	-	486.8	499.0	I
	L	-	487.2	501.7	I
2HzP,O	E	625.3	613.0	539.0	Decrease
	M	615.8	596.1	532.3	D
	L	603.7	587.0	519.2	D
2HzP,L	E	501.2	500.2	483.6	D
	M	499.9	491.1	485.4	D
	L	499.7	494.8	482.0	D
2HzP,R	E	506.9	491.7	475.3	D
	M	503.8	484.3	477.2	D
	L	503.1	486.6	474.4	D
2HzP,P	E	-	508.8	513.9	Increase
	M	-	499.8	511.5	I
	L	-	508.8	509.1	I
2HzD,O	E	529.7	536.3	486.1	I-Decrease
	M	525.8	528.5	482.6	I-Decrease
	L	513.7	519.5	472.3	I-Decrease
2HzD,L	E	503.4	503.7	491.6	D
	M	511.9	510.3	501.9	D
	L	517.7	507.7	496.4	D
2HzD,R	E	502.9	496.0	492.5	D
	M	509.7	504.0	500.9	D
	L	513.9	497.7	496.7	D
2HzD,P	E	-	499.5	507.2	Increase
	M	-	499.4	509.5	I
	L	-	501.1	508.7	I

Note. The unit of measure for the numbers is μV.

1 to year 2. Since the first analysis on the components demonstrated differences between them that were consistent over time, it was felt appropriate to look at the change in component variability within a given year. Table 5 gives the results of an analysis comparing the SDs of the early components to the SDs of the middle components and the SDs of the middle components to the SDs of the late components within year 1's data. Looking at the data in this fashion, similar findings to those in Table 3 are evident in that no significant differences in the SDs of the components of the 6 Hz VERs were obtained.

Whole VER Variability by Sex

Changes in variability over time as a function of sex were examined in an analysis of the whole VER SDs. Changes over the three years were examined separately for males and females at each stimulus condition and location, and an overall effect was assessed. As can be seen in Table 6, the overall effect was not statistically significant ($\underline{F}(18,58)=2.04$, $\underline{p} < .2565$). The individual analyses indicated statistically significant differences in variability change between males and females from year 1 to year 2 and from year 1 to year 3 at the right lobe location for the 6 Hz stimulus condition and at the occipital location for the 2 Hz diffuse stimulus location. Table 7 shows the mean SD for the sexes at each year for each VER and the direction of change.

Table 5

Significant SD Changes for Year 1 for Component VERs

Condition	Early-Middle	Middle-Late
6HzO		
6HzL		
6HzR		
2HzP,O	$F(1,75)=4.34$ $p < .0407$	$F(1,75)=8.79$ $p < .0041$
2HzP,L		
2HzP,R		
2HzD,O		$F(1,75)=8.98$ $p < .0037$
2HzD,L	$F(1,75)=5.00$ $p < .0283$	
2HzD,R	$F(1,75)=4.07$ $p < .0473$	

*overall $F(18,58)=2.04$, $p < .0213$

Table 6

Significant SD Changes Over Time for Whole VERs by Sex

Condition	Years 1-2	1-3
6HzO		
6HzL		
6HzR	$F(1,74)=6.24$ $p < .0147$	$F(1,74)=4.35$ $p < .0404$
6HzP		
2HzP,O		
2HzP,L		
2HzP,R		
2HzP,P		
2HzD,O	$F(1,74)=4.07$ $p < .0473$	$F(1,74)=4.78$ $p < .0320$
2HzD,L		
2HzD,R		
2HzD,P		

*overall $F(21,54)=1.24$, $p < .2565$

Table 7

Mean SDs and Directions of Change Over Time for Whole VERs by Sex

Condition	Sex	Year 1	Year 2	Year 3	Direction	Significant Difference By Sex
6HzO	Male	512.0	527.4	473.3	Increase-Decrease	
	Female	578.8	548.4	497.6	D	
6HzL	M	481.0	485.4	474.5	I-D	
	F	513.1	497.8	492.6	D	
6HzR	M	468.8	482.1	467.5	I-D	yrs. 1-2,
	F	523.1	485.1	482.5	D	1-3
6HzP	M	-	485.1	473.6	D	
	F	-	490.5	527.7	I	
2HzP,O	M	586.2	577.1	506.8	D	
	F	644:9	622.9	563.5	D	
2HzP,L	M	483.6	490.1	469.9	I-D	
	F	519.5	503.6	499.8	D	
2HzP,R	M	487.7	487.2	465.3	D	
	F	524.7	490.7	488.7	D	
2HzP,P	M	-	499.9	477.9	D	
	F	-	515.1	549.0	I	
2HzD,O	M	481.3	515.1	467.6	I-D	yrs. 1-2,
	F	562.3	539.8	492.0	D	1-3
2HzD,L	M	501.0	505.1	484.4	I-D	
	F	522.0	507.9	508.6	D-I	
2HzD,R	M	492.9	498.2	482.3	I-D	
	F	527.0	497.9	510.9	D-I	
2HzD,P	M	-	499.0	477.2	D	
	F	-	498.2	538.7	I	

Note. The unit of measure for the numbers is μV.

For the males, there was usually an increase in variability from year 1 to year 2 and a decrease from year 2 to year 3; in a few cases there was a consistent decrease across the three years. For the females, in most cases a steady decrease in variability was seen across years, except for the parietal lobe data, in which case an increase was seen from year 2 to year 3. This is in contrast to the males who demonstrated a decrease in variability from year 2 to year 3 at the parietal lobe location. Overall, in all conditions and years except two, the females showed more VER variability than the males.

SECTION IV
DISCUSSION

The results of this longitudinal study indicate significant changes in the variability (as measured by standard deviations) of VERs over time in 76 children from age five to age seven. Overall, change was characterized by a consistent, progressive decrease in variability over time with the major shifts between the ages of five and seven, and six and seven. VER variability changed between the ages of five and six, but not to a statistically significant degree, suggesting that changes in cortical processing as a function of age are not significant from age five to age six.

The major finding of a consistent change in variability as a function of time is positive with respect to the developmental research previously done in the VER area and with the predictions of this study. Callaway found in one study (Callaway & Halliday, 1973) that variability decreased with increasing age and later suggested that the change might be due to an increasing stability of cognitive functioning with age (Callaway, 1975). Other authors also found more variable EPs in children as compared to adults (Ellingson, 1970; Barnet

et al., 1975). The research leads to the prediction of a consistent change, most likely a decrease, in VER variability over time, possibly as a reflection of maturing cortical processing, and this prediction was supported by the findings in this study.

The single exception to the finding of decreasing variability as a function of age was in the parietal lobe location data which were obtained at ages six and seven only. At this electrode location VER variability increased from ages six to seven rather than decreased raising the interesting speculation that this area of brain functioning might be moving toward increasing flexibility or may not yet be matured. Studies in related areas of research provide possible partial explanations for this finding. From the results of animal studies, Lynch, Mountcastle, Talbot, and Yin (1977) conclude with the hypothesis that the parietal lobe performs a matching function between the neural signals of the nature of objects and the internal drive state of the organism, and also contains a neural apparatus for the direction of visual attention to objects of interest and for shifting attention. Perhaps parietal lobe functioning is more complex and involves a discriminatory function which either matures after the age of seven or fluctuates with development. Luria (1966) described the functions of different areas of the parietal lobe and they all involve some kind of

complex visual discrimination or integration. Thus, parietal lobe variability in this group of children appeared to be increasing, most likely due to an earlier stage of development of certain visually-related cognitive functions.

Preston et al. (1977) found VERs from the left parietal lobe location to be important in differentiating between groups of normal and disabled reading adults. Normal readers showed larger VER amplitude differences between a work and a flash condition at the left parietal lobe location as compared to disabled readers. The study basically supports earlier findings of decreased VER amplitude at the left parietal lobe location in disabled readers (Conners, 1970; Preston, Guthrie, & Childs, 1974). The evidence linking reading functions with VER measures from the left parietal lobe is compatible with the VER variability data derived from the left parietal lobe in this study. The increase in the measure of variability from age six to seven is suggestive of a currently active and developing process, such as reading, that is not yet stable and habitual in its pattern of functioning.

Although the overall significance level for the analysis of change in whole VER variability over time by sex was statistically low, the apparent differences are striking. In most cases, the females not only

demonstrated more variability within a given year at a given stimulus location and condition, but their variability change from year to year was more than that of the males. The change in the females followed the pattern of decreasing variability over time, whereas the males often demonstrated a non-linear change of an increase from age five to age six and then a decrease from age six to age seven. Apparently, the variability contributed by the females to the total sample masked, somewhat, the pattern of change in the males which differed substantially from the females. That the females demonstrated more VER variability than males in cortical processing overall possibly indicates more flexibility in processing at this age range, or it may be that a basic sex difference in the development of cortical processing exists. The difference between the sexes in the direction of the change in variability may reflect a difference in maturational stage of the cortical functions detected, possibly related to a basic sex difference in cortical function development. The males may be simply demonstrating a lag in which they begin to demonstrate similar cognitive processing by age seven.

The difference between the sexes in the change in variability at the parietal lobe location from age six to seven is of interest. The decrease in variability from age six to seven for the males parallels the pattern

of decrease the males showed at the other locations, but the increase in variability for the females is unique for them. As hypothesized previously, this increase may reflect an earlier stage of development of the cognitive functions detected at this location.

Also consistent in the data was a highly significant change in variability from age six to seven in the occipital location VERs. Although the visual system has supposedly reached physical maturity by this age, even the primary sensory system appears to be undergoing marked signal processing changes. However, a portion of the change seen at the occipital location may be more sensory in nature, since brain processing at this location is so closely linked to the visual sensory system.

It is somewhat difficult to explain that significant variability decreases were seen at the right lobe location for the 6 Hz diffuse and 2 Hz pattern conditions, whereas the significant changes for the 2 Hz diffuse condition were at the left lobe location. This may have to do with the known differences in functioning of the opposite hemispheres combined with the unique characteristics of the different stimulus conditions. The 6 Hz diffuse and 2 Hz pattern stimulus conditions may be thought of as slightly more complex in nature than the 2 Hz diffuse. Apparently, cognitive functioning in the right lobe

became significantly less variable in response to complex stimuli, while the left lobe's functioning became less variable to a simpler stimulus.

The lack of overall statistically significant change in differences in the variability of the early, middle, and late components of the VER over time indicates that, whatever the differences in cognitive functioning are as reflected by the different components, they do not reflect a significant difference in the flexibility of processing over time. There were differences within a year which may represent an artifact and/or contribute to difficulty in detecting differences between years. As might be expected, the variability over time within components follows the same general pattern as the overall VER variability changes (decreasing in all conditions except at the parietal lobe location). However, a consistent pattern of variability change across components within conditions is not apparent; in some cases variability increases, in some it decreases, and in some it is non-linear. Therefore, the hypothesis that early components would show less variability change over time than late components was not upheld. Evidently, at least for this sample, the variability of the components of any particular VER response does not reflect an easily detectable pattern of change in cognitive functioning.

The major finding in this study of a consistent, linear decrease in the variability of the whole VER response amplitude and its components complements and extends thought and work done in the area of cognitive development. As mentioned previously, thought in the developmental area points to changes in flexibility of cortical processing for proper adaptation to the environment. White (1965) discusses the nature of changes in children's learning processes which are known to take place during the range of five to seven years of age. He presents evidence for the idea of temporal stacking in several kinds of learning. The five to seven age period is perhaps a time when maturation inhibits a broad spectrum of lower level functioning in favor of a higher level of functioning. Literature is cited on several learning paradigms in children which stress the importance of the five to seven age range for changes in learning and thinking processes.

Piaget also stressed important changes from four to seven years of age (1962). During the intuitive phase of the preoperational period (two to seven years of age) the child begins to learn the concept of conservation. With maturity, the child learns to respond more flexibly and focuses on the more relevant aspects of an object or situation in order to attain conservation skills.

Some theories of individual cognitive style are also pertinent to the topic of response flexibility. Kagan's reflectivity-impulsivity dimension (Kagan, Rosman, Day, Albert, & Phillips, 1964) addresses the cognitive style differences between children who take the time and opportunity to try different alternatives and solutions to a task situation and those who impulsively respond after testing a limited number of hypotheses. In this context, a reflective, flexible cognitive style generally results in more accurate responding than a less varied one. Witkin's field dependence and independence (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962) refers to the tendency to perceive the perceptual field as undifferentiated versus the tendency to analyze the constituents of the field and perceive the different parts as separate from the field. Children are apparently more field dependent and this levels off by the teen years. The field independent cognitive style implies a more flexible mode of responding in that many parts of the picture are detected rather than the whole picture being detected as one configuration.

White's (1965) and Piaget's (1962) theories may be seen as conducive to a hypothesis of change, particularly one toward decreasing variability, in cortical functioning. Kagan et al. (1964) and Witkin et al. (1962) present ideas

that are more conducive to a hypothesis of increasing change in cortical functioning variability with age. Scott (1957) blends the two directions and suggests that higher organisms balance a tendency toward behaving variably and one toward behaving predictably. In a typical learning situation an individual needs to display a certain amount of variability in responding for proper adjustment, but later behaves more predictably when learning has occurred. Werner takes almost the opposite viewpoint (Langer, 1970) stating that the child first responds rigidly with reflex actions and then develops more flexibility in his worldly interactions.

The developmental literature on the developing stability or instability of cognitive organization is extensive. In general, authors agree that cognitive processing goes through some specific changes as the child matures, but they seem to be equally split as to whether increasing stability or flexibility is essential and primary to normal cognitive functioning. Of course, situations, conceptual constructs, and critical age periods vary across theories making comparison somewhat difficult. In this study, an obvious change in cortical processing was noted and at most stimulus conditions and locations variability was seen to decrease as a function of age. The change toward less flexibility implies that the cognitive functions reflected by the

measure utilized are becoming more narrow and efficient in nature, possibly due to a practice effect. The change may reflect a cognitive function that reached maturity at an earlier age and repeated use has shaped into an increasingly stable function. However, as discussed earlier, the VER data also reflected increasing variability in the parietal lobe location suggesting that functions in this area may be newly developing and, consequently, increasing in flexibility. Significant to the findings is the differing contribution by each sex to the overall variability measures. The differences in variability changes between males and females suggests a striking and stable difference in the development of cognitive functions at this age range.

The fact that the average IQ of these children was well above the average may also have influenced the perceived variability changes. Perhaps this group was somewhat advanced in the development of their overall cognitive functioning contributing to the detection of decreasing variability in most conditions. An investigation of a group of children with a lower average IQ, and one with the parietal lobe location measured for more than two years should certainly help clarify some of these issues.

In conclusion, this study demonstrated significant changes in the variability of cognitive processing as a

function of time as reflected by a measure of variability of the VER. Evidence is provided for the developmental hypothesis that brain functioning changes in flexibility as children grow older. Overall, the changes appear to be linear based on these data, although the changes decrease or increase depending on the brain location of collection of the VER. Patterns of variability change were also substantially different depending on sex of the subject. This finding has important indications for understanding child growth and development, and for understanding and managing specific development difficulties that appear to be sex-related, such as specific reading disability, which is more prevalent in males than in females (Wender, 1971).

The variability measure has provided a view of an aspect of child development that is often neglected: that of the flexibility of responding, which must necessarily change over time for appropriate growth and adaptation to the environment. Consistent patterns of change in variability were found implying that flexibility is an important and, possibly inherent, dimension of the normal growth and development of cognitive functioning. The finding of different directions of change depending on brain location supports the notion that different brain areas develop at different rates and that this is reflected in behavior. The implications for the difference in parietal lobe data,

depending on sex, to data relevant to the problem of disabled readers indicates the possible utility of this measure in the early detection of problems with cognitive functions that develop at different rates. The longitudinal data examined here provide the beginnings of needed baseline data for the overall normal changes in cognitive flexibility which may eventually be used to assess abnormal growth and related difficulties in the cognitive development of children.

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BIOGRAPHICAL SKETCH

Name: W. Jeanne Street

I was born on October 1, 1952, in Lexington, Virginia, in what was once the home of General Stonewall Jackson, was at the time of my birth a military hospital, and is now a museum to General Jackson. As my father was in the military service my family, which consisted of my parents, two older sisters, an older brother, and myself, moved and traveled quite a bit. I lived in Ohio, Alabama, West Germany, and Massachusetts before settling in Florida upon my father's retirement from the service in 1965. The moving and traveling had been fun and stimulating, but it was a welcome change to settle in one place.

I graduated from Clearwater High School, Clearwater, Florida, in 1970 after being involved in academics, student government, the school newspaper, and numerous community activities. Upon entering the University of Florida I concentrated my efforts on my education in psychology and received my B.A. in 1973, my M.A. in 1975, and now my Ph.D. in 1978 in clinical psychology. I did my clinical psychology internship at Duke University Medical Center, Durham, North Carolina, and am currently employed there in the Center for the Study of Aging and Human Development and the Division of Medical Psychology.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Nathan W. Perry Jr.

Nathan W. Perry, Jr., Chairman
Professor of Clinical Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Robert L. Isaacson

Robert L. Isaacson
Professor of Physiological Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Donald Childers

Donald Childers
Acting Chairman
Professor of Electrical Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Wiley C. Rasbury

Wiley Rasbury
Associate Professor of Clinical Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Vernon Van De Riet

Vernon Van De Riet
Associate Professor of Clinical Psychology

This dissertation was submitted to the Graduate Faculty of the Department of Clinical Psychology in the College of Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

March 1978

Dean, Graduate School